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LAGRANGIAN MEASUREMENTS OF SURFACE CIRCULATION IN THE ADRIATIC AND IONIAN SEAS BETWEEN NOVEMBER 1994 AND MARCH 1997

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Abstract

The near-surface circulation of the Adriatic and Ionian Seas is explored using Lagrangian drifting buoy measurements obtained between November 1994 and March 1997. The drifter trajectories reveal the complex and highly variable structure of the surface currents. The main pathways of the surface waters are defined and the major persistent surface circulation features are described. The seasonal variability of the surface currents is studied in the sea areas with maximum drifter data density, namely, in the Sicily Straits, the Northern Ionian, the Otranto Straits and the Southern Adriatic.

Key-words: Circulation, Surface Waters, Eastern Mediterranean

Introduction

The advent of efficient worldwide satellite tracking and telemetry systems in the late 1970's marked the beginning of Lagrangian measurements of ocean currents (and other parameters such as temperature and salinity) using expandable freely drifting buoy systems. Because of the direct wind/wave effects on their top elements (*e.g.*, the transmission antenna and other instruments) emerging at the sea surface, surface drifters do not follow the surface currents exactly. The downwind drifter movement with respect to the sea water, or slippage, can become substantial in high seas. Slippage problems were particularly important for the early drifter experiments (*e.g.*, the FGGE drifters in the Antarctic Circumpolar Circulation). They provided the impetus for the design of various buoy systems that provide maximum adherence to the sea water. Designs such as the CODE, the TRISTAR and the WOCE/TOGA SVP (holey sock) were developed in the 1980's. Calibration experiments [1] revealed that their relative slip with respect to the water only amounts to a fraction of one percent of the surface wind speed.

Drifter data in the Mediterranean Sea

Deployments of satellite-tracked drifters (with good water-following capabilities) in the Mediterranean started in the late 1980's as part of regional scientific surveys and operational military operations. Seeding continued into the 1990's when dedicated basin-wide drifter programs were conducted in the Ionian and in the Adriatic [2]. Most of these data sets have been quality controlled and combined in a common data base. The drifter data were processed to obtain low-pass filtered (36 hour cut-off) series of position (latitude and longitude), velocity (zonal and meridional components) and other ancillary parameters such as sea surface temperature at regular 6 hour intervals. The data of 112 modified CODE drifters extending within the first meter of water [2] and 6 WOCE/TOGA SVP drifters drogued to 15 m [1] for the time period between November 1994 and March 1997 are considered in this paper. Their low-pass filtered trajectories are depicted in Fig.1. The complexity of the sub-tidal surface currents patterns is striking. The tortuous drifter trajectories are the result of both spatial and temporal variability. Besides the strong mesoscale signal, in form of eddy, meander and filament patterns, significant seasonal variability is included in this Lagrangian drifter data.

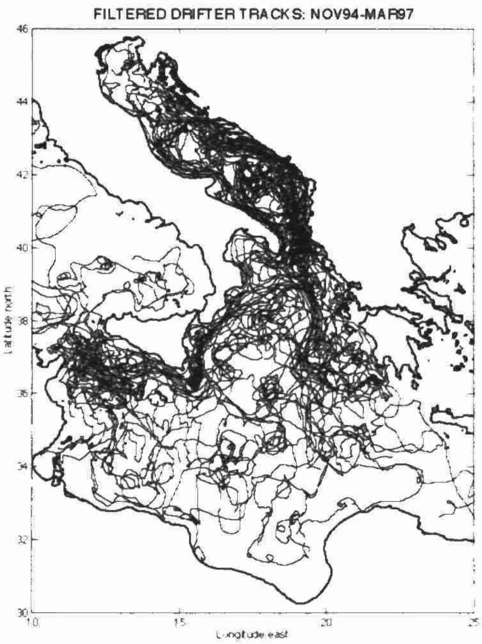

Fig. 1. Composite diagram of the low-pass filtered surface drifter trajectories in the Adriatic and Ionian Seas from November 1994 to March 1997. Arrows are only plotted in the bins sampled by the drifters.

Drifter trajectories

The composite "spaghetti" diagram of the low-pass filtered trajectories (Fig. 1.) in the Adriatic and Ionian Seas discloses some of their well-known persistent circulation features, such as the Atlantic Ionian Stream in the Sicily Straits and the northwestern Ionian, and the basin-scale cyclonic circulation gyre in the Adriatic. The Atlantic Ionian Stream is evident as a swift current flowing southeastward in the Sicily Straits, passing through the Malta Channel and extending into the northwestern Ionian where the mean circulation is mostly anticyclonic. South of this strong current, the Modified Atlantic Water flows southeastward and mostly recirculates on the Tunisian shelf, hence contributing very little to the mean inflow into the Ionian. Upon leaving the shelf east of Malta, Modified Atlantic Water bifurcates into a northward main swift branch and slower eastward and southward components. Recirculating cyclonic gyres are evident between the Sicilian coast and the strong northward branch. In the Adriatic, the classical basin-wide mean cyclonic circulation [3] with northwestward (southeastward) currents on the eastern (western) side, actually composed of two sub-basin cyclonic, circulatory patterns around the two main topographic deeps of the Adriatic, is confirmed by the drifter measurements.

The drifters reveal a novel structure of the Ionian surface circulation in which the Modified Atlantic Water appears to transit eastward in three different ways (Fig. 1): (1) As a strong anticyclonic mean loop current in the northern part of the basin extending into a concentrated southward-flowing limb west of Greece. This meridional jet in the northeast Ionian is in good agreement with circulation maps derived from hydrographic observations in the late 1980's [4]. Further south, drifters either move to the southeast and eventually get caught in the Pelops anticyclonic gyre southwest of the Peloponese Peninsula, or meander to the south towards Libya; (2) in the form of weak and chaotic currents in the central Ionian; and (3) as a relatively swift coastal circulation off the African continent, known as the African Current. The anticyclonic circulation pattern in the northern Ionian extends as far north as about 39°N where a confluence zone appears between the Modified Atlantic Water and the Adriatic Surface Water outflowing through the Otranto Straits. The latter water joins the main anticyclonic circulation either directly or after a cyclonic loop in the Gulf of Taranto.

Mean Circulation Maps and Seasonal Variability

The seasonal variability of the surface circulation was studied in areas of the Mediterranean Sea where the number of drifter observations is relatively large and well distributed over the seasons, i.e., in the Straits of Sicily, the Northern Ionian, the Otranto Straits and the Southern Adriatic. In order to map the mean surface circulation, the low-pass filtered drifter velocities were averaged in bins of 0.25° latitude by 0.25° longitude for each season. The mean circulation maps for winter, spring, summer and fall are presented in Figs. 2a,b,c,d, respectively. Arrows represent the mean velocities in bins sampled by the drifters. The deployment strategy adopted and the Lagrangian nature of the drifters combined to produce different non-uniform data coverages for the four seasons. Note that the southwest Adriatic and the northern Ionian have very few observations in spring.

In the Sicily Straits, the inflow of Modified Atlantic Water seems to be maximum in summer and minimum in winter in good agreement with geostrophic estimates reported in the literature [5]. In spring, summer and fall, most drifters proceeded eastward through the Malta Channel and upon leaving the Malta Shelf separated into three branches, the northernmost one corresponding to fast northward-northeastward currents following the sharp Ionian shelf break and forming a mean anticyclonic gyre in the Northern Ionian. This anticyclonic sense of rotation also persisted into winter, in some contradiction with hydrographic observations [6] and computer simulations that indicate alternate anticyclonic and cyclonic patterns in summer and winter, respectively. In winter, the drifters deployed upstream in the Sicily Straits tended to avoid the Malta Channel route and

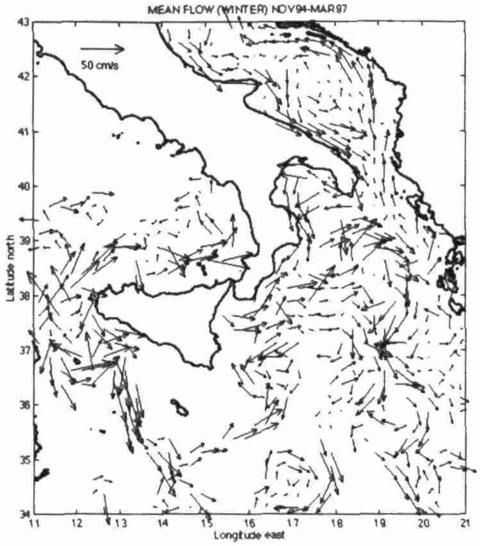

Figure 2a.

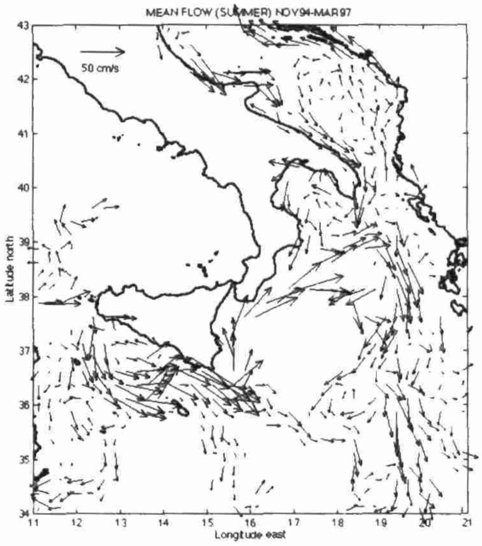

Figure 2c.

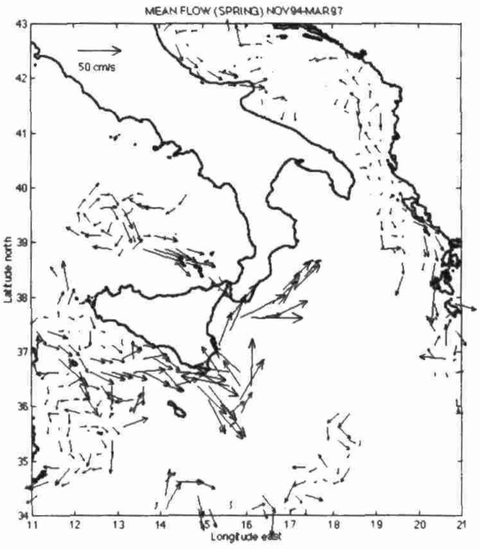

Figure 2b.

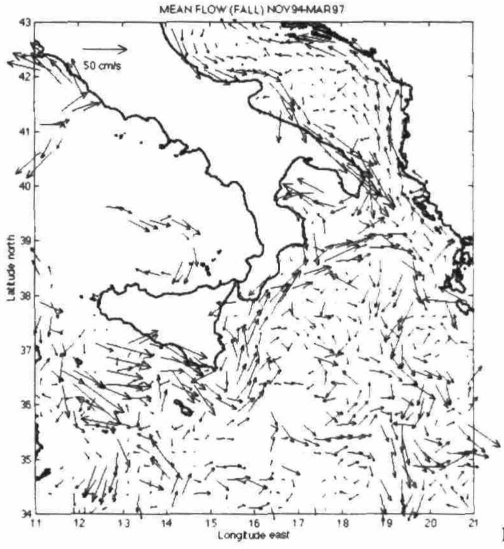

Figure 2d.

Fig. 2. Seasonal maps of the surface mean circulation as estimated in 0.25° x 0.25° bins from the entire drifter dataset: winter (a), spring (b), summer (c) and fall (d).

proceeded south-southeastward eventually reaching the central Ionian. Some sub-basin scale cyclonic features are apparent in the northern Ionian in winter (*e.g.,* at 16.5°E and 36.5°N) but the general circulation is still influenced by a general anticyclonic circulation.

An enhanced horizontal shear (northward flow on the eastern flank and southward currents on the western side) at the entrance of the Adriatic Sea (Otranto Straits) and an increased cyclonic gyre circulation in the Southern Adriatic were observed in fall and winter (Fig. 2a). The inflow of Ionian water and the subsequent cyclonic veering around the South Adriatic Pit are minimum in spring. During this season, the outflow of surface Adriatic water in the western Otranto Straits was not sampled by the drifters. In summer, the south outflowing currents on the Italian shelf are maximum (Fig. 2b).

Conclusion

Direct surface current measurements obtained by tracking freely-drifting buoy systems over a few years provided the first global description of the surface circulation in the Adriatic and Ionian Seas. The drifter results confirmed the major current patterns already known from water mass and Eulerian current studies. In addition, they revealed new important aspects of the spatial structure and seasonal variability of the surface currents. Lagrangian data were shown to be an important ingredient that, combined with other *in-situ* Eulerian and remotely sensed observations and numerical simulation exercises, should be used to study the dynamics of the Mediterranean Sea.

Acknowledgments

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